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Ponderosa Pine

November 28, 1942

GROWTH OF PONDEROSA PINE BY KEEN TREE CLASS

By

Philip A. Briegleb
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During the field seasons of 1938 and 1939 thirty 10-acre permanent sample plots were established in typical virgin ponderosa pine stands in central and eastern Oregon by the Portland office of Forest Insect Investigations, Bureau of Entomology and Plant Quarantine. (See figure 1.) On these plots each ponderosa pine tree 9.6 inches and larger in diameter was numbered and tagged, carefully classified by the Keen tree class system, measured for diameter at breast height, and for total height; in addition, an increment core was extracted from each. A total of almost 8,000 sample trees were taken.

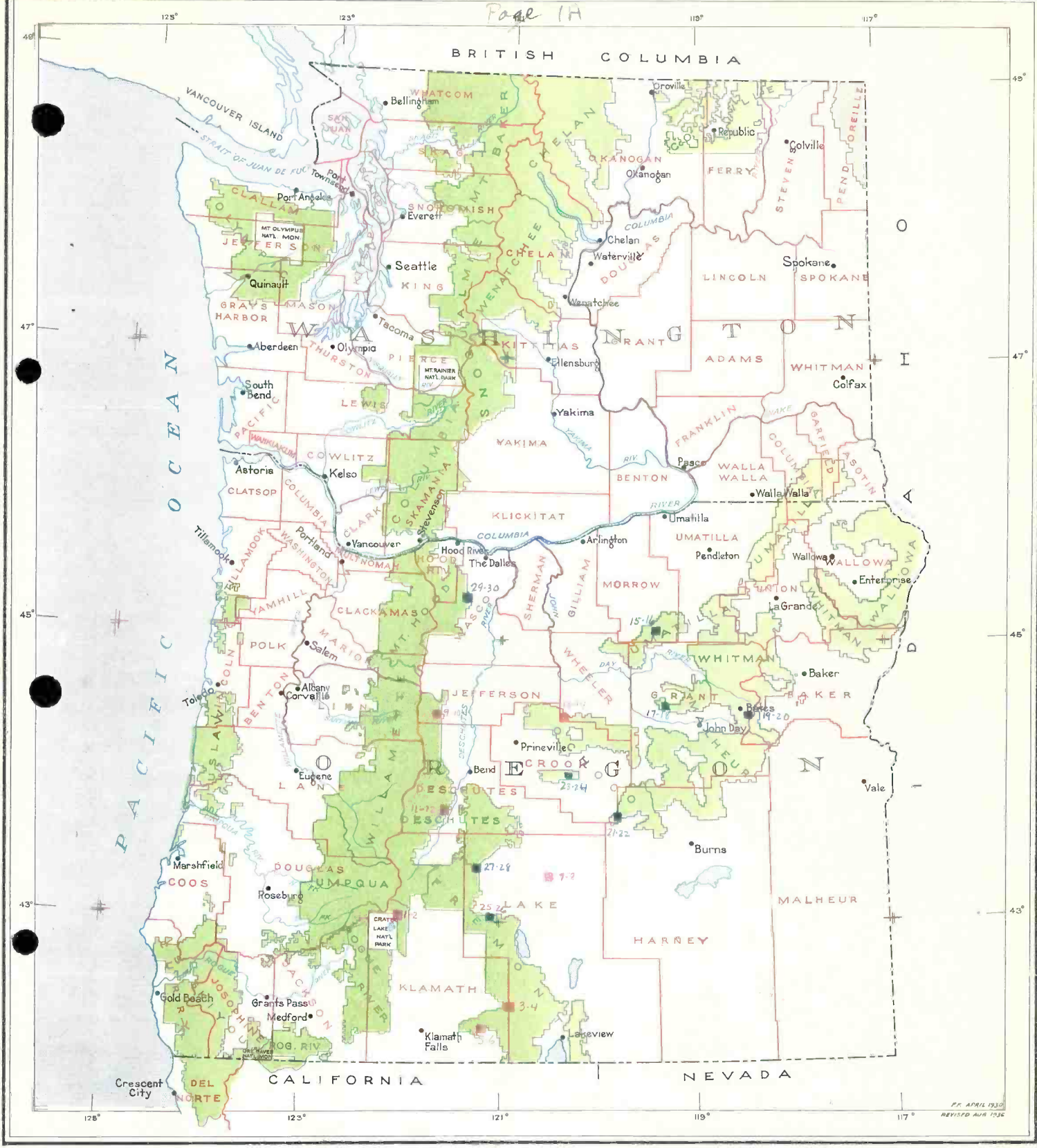
In time these plots will yield accurate and comprehensive growth and mortality experience records for trees of the 16 Keen tree classes. In the meanwhile the records of past growth on the increment cores provide a basis for computing growth expectancies for immediate use. The radial growth on these cores was measured and compiled by Jack Huber, Bureau of Entomology and Plant Quarantine, during the years 1939 and 1940. Core measurements were made by microscope micrometer, decade by decade, back from the time of extraction and were recorded in terms of millimeters.

Early in the year 1941 the compiled core measurements were made available for analysis to the Pacific Northwest Forest and Range Experiment Station. By spring the basic computations were well advanced when the work was interrupted by lack of computing help that resulted from shrinkage in the Station's WPA project. Pressure of other high-priority work prevented resumption of this project until the past two weeks.

In general, analysis followed the routine outlined in "Working Plan for Analysis of Growth Rate of Ponderosa Pine by Keen Tree Class", November 13, 1940, by P. A. Briegleb. Some of the significant details of the analysis and occasional departures from the intended plan are described in the appendix of the present report, as are some characteristics of the basic data.

Factors Affecting Growth of Individual Trees

Two of the principal factors affecting growth of ponderosa pine trees are (1) tree class, i. e. age class and vigor class, and (2) diameter or size class. The influence of these two factors, as found in this study, is shown in detail in the following tables 1 to 6 and figures 2, 3, and 4.



LEGEND

- STATE LINES
- NATIONAL FORESTS
- COUNTY BOUNDARIES

PACIFIC NORTHWEST FOREST EXPERIMENT STATION

Project *LOCATION OF PERMANENT 10 ACRES SAMPLE PLOTS*

BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE

Plots 1-14 ESTABLISHED 1938

Plots 15-30 ESTABLISHED 1939

FIGURE 1

Other important factors that influence the growth of individual trees, and which are discussed in turn, are: (3) Growth cycles; (4) site quality; and (5) stand competition, or stocking.

Diameter Growth by Tree Class

If all tree classes were equally represented in a virgin stand the normal growth in diameter would average about three-quarters of an inch per decade. The youngest, most vigorous trees in the stand, the 1A's, would be expected to make double the average diameter growth, or about one and one-half inches in 10 years.

In contrast the oldest, least vigorous trees, the 4D's, would be expected to grow at only about one-quarter inch per decade. See table 1 and figure 2, which show the normal diameter growth rates for each of the 16 tree classes.

Diameter Growth by Tree Class and Diameter Class

Within some of the tree classes the normal diameter growth rates vary considerably, depending on tree diameter. (See table 2.) For the young and the vigorous trees as a group, i.e. tree classes 1A, 1B, 2A, and 2B, normal diameter growth diminishes as tree size increases. As these young, vigorous tree classes increase in size they grow into competition as is evidenced by their declining growth rates. In addition, the larger trees in any one tree class tend to be older than the class average, and are subject to the general regression of growth on age. *age?*

For trees of corresponding good vigor in the advanced age classes, i.e. the 3A's, 3B's, 4A's, and 4B's, the relation of tree size to diameter growth rate is quite the reverse. As these classes increase in diameter they are growing out of competition and greater diameter growth rates are associated with the larger size classes. Although the larger individuals in these tree classes also tend to be older than the class average this effect is not sufficient to result in reduced growth rates.

The D-crown trees in all age classes, those of very poor vigor, consistently show a decline in diameter growth with increase in size, a trend that might logically be associated with increasing age and increasing competition with more vigorous stand associates.

In all C-vigor classes, trees of fair to poor thrift, diameter growth rate is independent of tree size. Although the larger trees in these classes are older than their class average, there is a compensating tendency for such trees to be more vigorous than their class mean.

The diameter growth rates shown in table 2 may be converted to terms of volume increment through the medium of a volume table based upon any log rule or other standard of measurement that may be chosen, such as cubic feet, cords, or lumber tally.

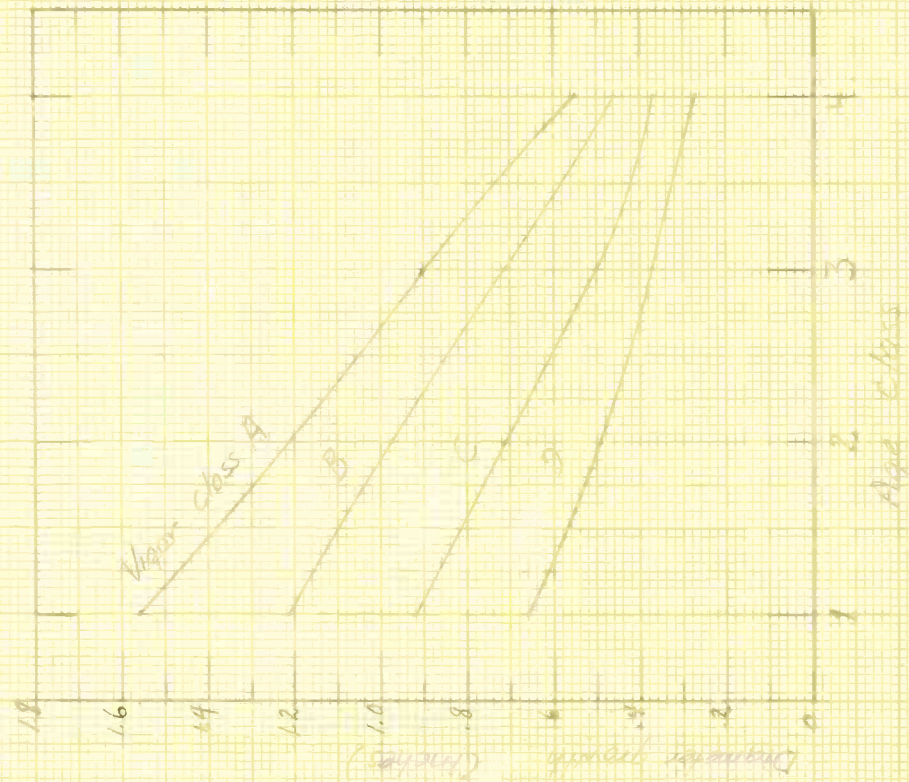


Figure 2. Annual diameter growth in diameter at breast height (inches) for the four classes.

Table 1.--Normal 10-year Growth in Diameter at
Breast Height, Outside Bark, by Tree Class

Age class	Vigor class				Unweighted average
	A	B	C	D	
	<u>Inches</u>	<u>Inches</u>	<u>Inches</u>	<u>Inches</u>	<u>Inches</u>
1	1.56	1.21	.92	.66	1.09
2	1.21	.97	.71	.49	.84
3	.90	.71	.50	.37	.62
4	.55	.46	.37	.27	.41
Unweighted average	1.06	.84	.62	.45	.74

Table 2.--Normal 10-year Growth in Diameter at Breast Height Outside Bark
by Tree Class and Diameter Class

Diam. at B. H. In.	Tree class				Tree class				Tree class				Tree class			
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	3C	3D	4A	4B	4C	4D
	Inches				Inches				Inches				Inches			
10	1.69	1.28	.92	.66	1.50	1.14	.71	.49			.50	.41				.32
12	1.60	1.21	.92	.64	1.42	1.07	.71	.49			.50	.39				.31
14	1.51	1.13	.92	.63	1.34	1.01	.71	.47		.57	.50	.38			.37	.30
16	1.42	1.06	.92	.61	1.28	.97	.71	.46	.73	.60	.50	.36			.37	.29
18	1.33	.99	.92		1.23	.93	.71	.45	.76	.64	.50	.34	.38		.37	.28
20	1.24	.93			1.16	.90	.71	.44	.80	.66	.50	.33	.39		.37	.27
22	1.15				1.13	.88	.71		.83	.68	.50	.31	.41		.37	.26
24					1.11	.86	.71		.86	.70	.50	.29	.48	.42	.37	.25
26					1.09	.84	.71		.88	.72	.50	.28	.50	.43	.37	.25
28					1.08	.83			.90	.74	.50	.26	.51	.45	.37	.24
30					1.06	.82			.92	.76	.50	.24	.52	.46	.37	.23
32					1.04				.94	.77	.50		.54	.46	.37	.22
34									.96	.78	.50		.55	.47	.37	.21
36									.97	.79	.50		.56	.48	.37	.20
38									.99	.79	.50		.57	.49	.37	.19
40									1.00	.80			.58	.50	.37	.19
42									1.01	.81			.59	.50	.37	
44									1.02	.81			.59	.51	.37	
46									1.02				.60	.51	.37	
48													.60	.52	.37	
50													.61	.52		
54													.62			
58													.62			

Volume Growth by Tree Class and Diameter Class

Tables 3 and 4 show the normal 10-year volume growth per tree in board feet, Scribner rule, and in cubic feet respectively. These were obtained by applying the diameter growth rates shown in table 2 to the range-wide standard ponderosa pine volume tables. The tree heights employed in this procedure were obtained from a set of coordinated height curves prepared by F. P. Keen and R. C. Grant, using over 7,000 height measurements taken on the plots on which this study is based. The curve corresponding to middle site IV, the average site quality of the plots, was employed.

Ponderosa pine trees may be expected to put on an increment of from 6 to 177 board feet, or from 1 to about 25 cubic feet per decade, depending on their size, age, and vigor.

It is evident that for trees of identical d.b.h. and height the volume growth is much greater the younger the age class and the better the vigor class. In general the volume growth per tree for any one tree class increases with tree size, as would be expected. The one exception is found in the 4D class, the slowest-growing of all, in which growth per tree increases up to the 30-inch diameter and thereafter gradually declines.

The gross growth of virgin ponderosa pine stands can be computed by applying the growth rates per tree given in tables 3 and 4 to a stand table showing number of trees by Keen tree class and by d.b.h. class.

Volume Growth Percent

If volume growth per tree is divided by tree volume at the start of the growth period and multiplied by 100, the result is increment as a simple percentage of the tree volume to which it is added. In this way tables 5 and 6, showing normal annual growth as percent of board-foot and of cubic-foot volume respectively, were derived from tables 3 and 4.

Annual growth percents range from .12 to 7.93 percent of board-foot volume; from .07 to 5.65 percent of the cubic-foot.

For trees of the same size, growth percent is greater the younger the age, the better the vigor without exception. For any one tree class growth percent is smaller the greater the diameter, also without exception. These trends are vividly revealed in figures 3 and 4 for age class 3 and for vigor class B trees respectively.

Gross growth of virgin ponderosa pine stands can be computed by applying the growth percentages given in tables 5 and 6 to a stock table showing volume by tree class and by d.b.h.

It is this expression of growth that is employed along with mortality probability and net value for computing the priority of cutting of ponderosa pine according to the maturity selection theory.

Figure 3 Normal annual growth as percent of board-foot volume for age-class 3 trees, by vigor class and diameter

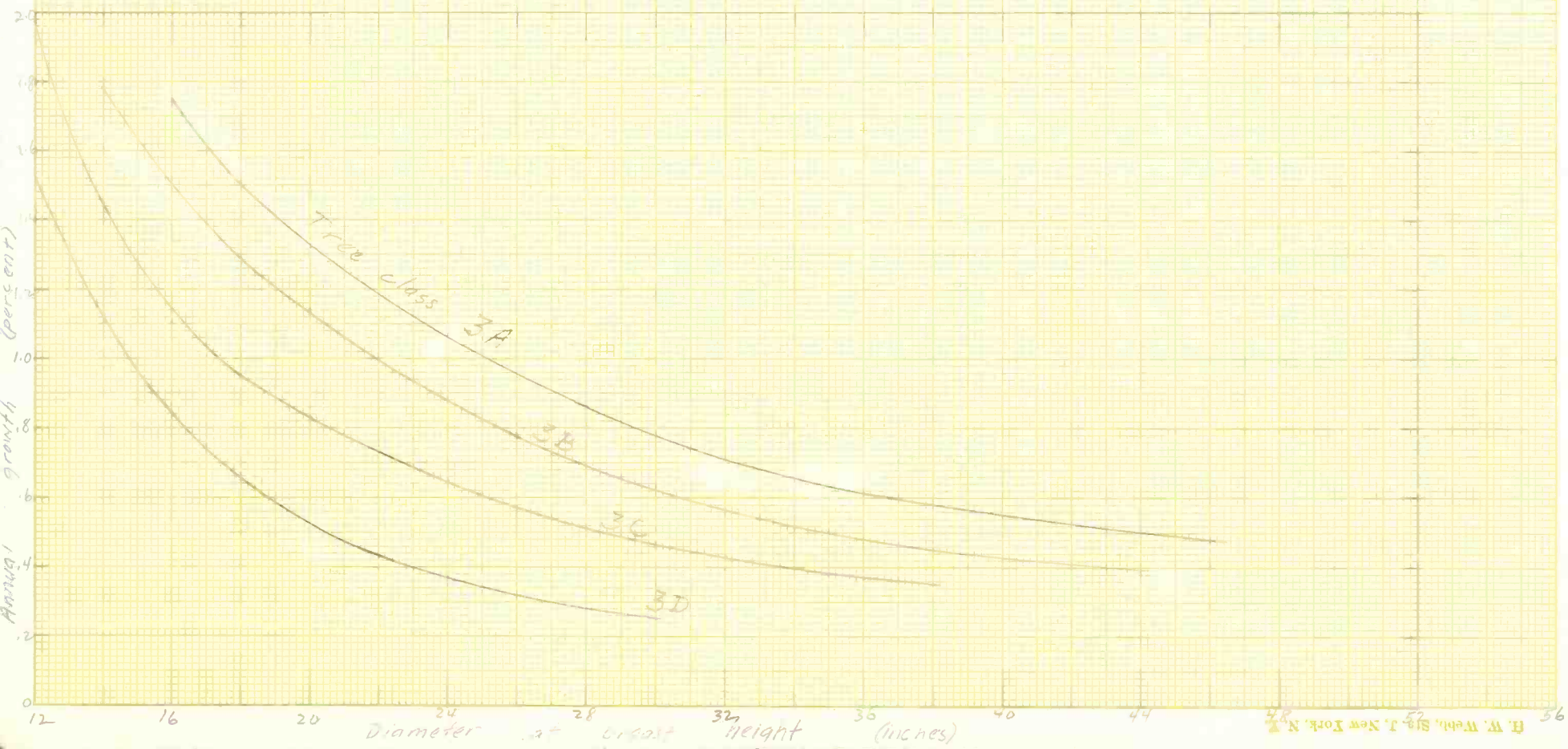


Table 3.--Normal 10-year Growth in Board Feet Per tree
by Tree Class and Diameter Class

Diam. at B. H. In.	Tree class				Tree class				Tree class				Tree class			
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	3C	3D	4A	4B	4C	4D
	Board Feet, Scribner Rule															
10																6
12	38	28	22	15	25	19	15	11			12	9				9
14	49	36	30	21	39	30	22	16		20	16	12			10	9
16	56	43	37	25	48	37	27	18	31	27	20	15			14	12
18	66	50	45		58	45	34	22	40	34	25	17		19	16	14
20	75	57			68	52	40	24	50	42	31	19		24	19	16
22	83				76	58	46		60	51	37	22		30	22	18
24					85	65	54		71	58	43	24	41	36	26	19
26					93	70	60		82	66	48	27	48	43	30	20
28					100	76			92	74	55	30	57	51	34	21
30					106	83			102	81	61	33	65	58	40	24
32					111				108	89	67		70	64	44	25
34									119	99	73		75	68	46	26
36									129	108	78		81	72	51	28
38									138	114	85		85	75	56	31
40									150	120			88	79	57	33
42									162	122			92	82	61	
44									168	128			94	84	64	
46									177				96	85	66	
48													102	86	69	
50													112	89		
54													125			
58													144			

Table 4.--Normal 10-year Growth in Cubic Feet Per Tree
by Tree Class and Diameter Class

Diam. at B. H. In.	Tree class				Tree class				Tree class				Tree class			
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	3C	3D	4A	4B	4C	4D
	Cubic feet				Cubic feet				Cubic feet				Cubic feet			
10	5.7	4.1	2.9	2.1	4.7	3.6	2.1	1.6			1.7	1.4				1.0
12	7.3	5.3	4.0	2.8	6.1	4.7	2.9	2.1			2.4	1.8				1.4
14	8.7	6.4	5.1	3.4	7.5	5.6	3.7	2.7		3.9	3.0	2.3			2.1	1.8
16	10.1	7.4	6.3	4.1	9.0	6.6	4.8	3.3	5.4	4.8	3.6	2.6			2.4	2.1
18	11.6	8.4	7.6		10.4	7.6	5.8	3.8	6.9	5.8	4.5	3.1		3.7	2.9	2.5
20	12.4	9.2			11.6	8.5	7.0	4.3	8.2	6.9	5.3	3.4		4.3	3.3	2.9
22	13.2				12.5	9.2	8.0		9.8	7.9	6.1	3.8		5.1	3.9	3.2
24					13.3	9.9	8.9		11.3	9.0	7.0	4.0	6.5	5.8	4.3	3.4
26					13.9	10.5	9.4		12.6	9.6	7.6	4.1	7.3	6.4	4.8	3.4
28					14.3	11.1			13.7	10.2	8.4	4.4	8.3	7.0	5.3	3.5
30					14.9	11.7			14.8	10.7	9.2	4.4	9.0	7.7	5.6	3.6
32					15.3				15.9	11.2	9.8		9.8	8.5	6.1	3.4
34									16.9	12.1	10.7		10.4	9.0	6.8	3.4
36									18.1	13.3	11.3		11.0	9.7	7.5	3.2
38									19.6	15.2	12.2		11.8	10.4	7.8	3.0
40									20.6	16.5			12.4	10.7	8.2	2.9
42									22.0	17.4			13.3	11.0	8.3	
44									23.4	18.8			13.7	11.7	8.6	
46									24.6				14.5	12.3	8.9	
48													15.2	12.8	9.1	
50													16.5	13.2		
54													19.2			
58													22.2			

Table 5.--Normal Annual Growth as Percent of Board-foot Volume
by Tree Class and Diameter Class

Diam. at B. H. In.	Tree class				Tree class				Tree class				Tree class			
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	3C	3D	4A	4B	4C	4D
	Percent				Percent				Percent				Percent			
10																
12	7.93	5.85	4.50	3.15	5.25	4.05	3.10	2.30			1.97	1.52				1.00
14	4.85	3.57	2.94	2.02	3.80	2.90	2.14	1.55		1.78	1.45	1.12			.95	.81
16	3.38	2.62	2.25	1.49	2.88	2.24	1.66	1.12	1.75	1.50	1.14	.84			.77	.67
18	2.63	2.00	1.80		2.33	1.79	1.35	.86	1.51	1.29	.95	.65		.73	.61	.54
20	2.14	1.62			1.94	1.49	1.14	.70	1.32	1.13	.83	.52		.65	.51	.43
22	1.78				1.64	1.25	1.00		1.18	1.00	.73	.43		.59	.44	.35
24					1.40	1.06	.88		1.06	.88	.65	.37	.62	.55	.39	.28
26					1.21	.91	.78		.96	.78	.57	.32	.57	.51	.35	.23
28					1.05	.80			.86	.69	.51	.28	.53	.48	.32	.20
30					.92	.72			.78	.62	.46	.25	.49	.44	.30	.18
32					.82				.71	.57	.43		.45	.41	.28	.16
34									.66	.52	.40		.41	.37	.25	.14
36									.61	.48	.37		.38	.34	.24	.13
38									.58	.45	.35		.35	.31	.23	.13
40									.55	.43			.32	.29	.21	.12
42									.52	.41			.30	.27	.20	
44									.50	.39			.28	.25	.19	
46									.48				.26	.23	.18	
48													.25	.21	.17	
50													.25	.20		
54													.24			
58													.24			

Table 6.--Normal Annual Growth as Percent of Cubic-foot Volume
by Tree Class and Diameter Class

Diam. at B. H. In.	Tree class				Tree class				Tree class				Tree class			
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	3C	3D	4A	4B	4C	4D
	Percent				Percent				Percent				Percent			
10	5.65	4.05	2.90	2.08	4.65	3.55	2.10	1.58			1.46	1.15				.86
12	4.29	3.14	2.36	1.62	3.58	2.74	1.72	1.26			1.24	.96				.72
14	3.35	2.47	1.96	1.29	2.87	2.15	1.44	1.04		1.28	1.05	.80			.73	.62
16	2.67	1.95	1.65	1.08	2.36	1.74	1.25	.86	1.34	1.14	.90	.66			.60	.53
18	2.18	1.58	1.44		1.97	1.44	1.10	.72	1.22	1.03	.80	.55		.65	.52	.45
20	1.77	1.32			1.65	1.21	1.00	.61	1.11	.93	.71	.46		.58	.45	.39
22	1.48				1.40	1.03	.90		1.02	.83	.64	.40		.53	.41	.33
24					1.20	.89	.80		.94	.75	.58	.33	.54	.48	.36	.28
26					1.03	.78	.70		.86	.66	.52	.28	.50	.44	.33	.23
28					.89	.69			.78	.58	.48	.25	.47	.40	.30	.20
30					.79	.62			.71	.51	.44	.21	.43	.37	.27	.17
32					.71				.65	.46	.40		.40	.35	.25	.14
34									.60	.43	.38		.37	.32	.24	.12
36									.56	.41	.35		.34	.30	.23	.10
38									.53	.41	.33		.32	.28	.21	.08
40									.50	.40			.30	.26	.20	.07
42									.48	.38			.29	.24	.18	
44									.46	.37			.27	.23	.17	
46									.44				.26	.22	.16	
48													.25	.21	.15	
50													.25	.20		
54													.25			
58													.25			

The Effect of Growth Cycles

Rates shown in the accompanying tables and figures are estimates of average increment during periods of so-called "normal" growth, which are believed to be associated with normal rainfall. Wide periodic variations in rainfall and in forest growth are typical of the ponderosa pine belt. The growth that is actually put on during any specific decade may surpass or fall short of the expected by a wide margin, perhaps as much as 40 percent, depending upon rainfall excess or deficiency, whichever occurs. Fortunately for longer periods these wide discrepancies tend to compensate.

Poor growth periods do not affect all tree classes to the same extent. This is clearly shown in table 7, which gives annual diameter growth from 1929 to 1938 (a period of exceptionally poor increment) as percent of that made during the years 1900 to 1929 inclusive, a period selected as approximating normal growth.

Trees of the low vigor classes suffered a greater relative reduction in growth during unfavorable periods than did the more vigorous trees. Among the vigorous trees the greatest reduction occurred in the older age classes but among those of poorest thrift the reverse is true.

Table 7.--Annual Diameter Growth, 1929 to 1938, as Percent of That Made During the Period 1900-29, By Tree Class

Age class	Vigor class				Weighted average
	A	B	C	D	
	Percent	Percent	Percent	Percent	Percent
1	69.0	66.0	60.6	48.0	62.0
2	65.8	62.3	57.5	47.0	61.4
3	63.5	59.9	56.5	50.5	55.7
4	62.5	60.0	58.9	57.1	59.7
Weighted average	64.4	59.9	56.9	51.2	58.3

Effect of Site Quality

Site quality of the plots used in this study averages class IV, which is representative of about two-thirds of the ponderosa pine lands in central and eastern Oregon and Washington. In site index units the plots averaged 77 feet.

On better and on poorer sites the growth rates are higher and lower respectively than those given above. For example, the normal rates of diameter growth on site III land are 10 percent greater than the rates shown in tables 1 and 2 for site IV. The rates on site V are 10 percent less than those tabulated. In terms of board-foot volume, the growth on site III is 125 percent of the normal for site IV; that on site V is but 75 percent.

The effect of site on growth is not uniform at all times. During favorable climatic or growth cycles the difference in growth rate between good and poor sites diminishes; during periods of poor growth the difference is accentuated. Conversely, the effect of growth cycles is more pronounced on poor sites than on the good.

This logical relation of productive capacity is shown in table 8 which gives the relative diameter growth rates made on site quality classes III, IV, and V during a normal, a severely subnormal, and a somewhat supernormal growth period. During the 1929 to 1938 period of slow growth, increment on site IV dropped to 58 percent of its normal rate. Growth on site V fell to 51 percent ($46 \div 90$) of its normal, but that on site III was less drastically reduced to 65 percent of its normal rate. During the 1900-19 period, growth on site IV was increased about 10 percent above its normal level, that on site V 12 percent, but on site III tree diameters increased only 8 percent more rapidly than normally.

Table 8.--Diameter Growth as Percent of That Made
On Site IV Lands During Normal Growing Cycle,
by Site Quality Class for Three Growth Periods

Site quality class	Growth period		
	Normal (1900-1929)	Subnormal (1929-1938)	Supernormal (1900-1919)
	Percent	Percent	Percent
III	110	71	119
IV	100	58	110
V	90	46	101

The effect of site index on diameter growth rate during three segments of the growth cycle is expressed mathematically in the three equations given in table 9. Joint association between site index and growth cycle is revealed by variation in the coefficients of site index. They range from

.5511 for a period of good growth, when increment on all sites is more nearly the same to 1.5020 for a severely subnormal period during which the effect of site was emphasized.

Table 9.--Equations for Correcting Diameter Growth Estimates for Differences in Site Index

Growth period	Growth cycle	Correction equation for site index
1900-1929	Assumed normal	Correction = $46.403 + 0.7298$ site index (Pet.)
1929-1938	Severely subnormal	Correction = $-15.390 + 1.5020$ site index (Pet.)
1900-1919	Slightly supernormal	Correction = $60.034 + 0.5511$ site index (Pet.)

Effect of Stand Competition on Tree Growth

Growth of an individual tree depends not only on its own age, vigor, size, and on the productive capacity of its site, but it is also influenced by the number, the size, proximity, and competitive ability of its neighbors. In the present study, however, no satisfactory quantitative measure of this effect could be found. From these data, for example, it could not be shown that growth of individual trees is systematically related to the total volume per acre of the stand in which they grow, although this relation has been found significant and substantial in several previous growth studies in the region.

For one thing, the present data are not particularly suitable for accurately defining this effect. Although nearly 8,000 sample trees are represented, only 30 plots, 30 samples of stand competition are included. On these 30 plots, stand volume per acre is quite closely correlated with productive capacity or site index, their correlation coefficient being 0.713. Within any one site index class, the range in volume per acre is small; within any volume class there is little variation in site. Hence, the net effect of either factor on growth is somewhat confused by close association with the other.

There is another reason why effect of stand competition as such is poorly defined by the present study. A large part of the variation in growth has been accounted for by tree class and tree size, two factors that are associated with existing as well as with past competition in an uncut forest. The effect on growth of the change in stand competition, brought about by cutting, must be sought in stands that have been cut.

APPENDIX

Basic Data

General characteristics of the basic data have already been described. Detailed location of each plot, the number of trees on each, its site index, and gross volume per acre are given in table 10. The total number of trees studied on all plots is summarized by tree class in table 11, their average diameter in table 12. The total number of trees on all plots does not agree with the total number analyzed as shown in table 11. Table 10 gives the number of trees 9.6 inches or 7.6 inches and larger in d.b.h. (depending on plot number) at the time of establishment. Of the trees found at that time, table 11 shows the number that were 7.6 inches or larger in d.b.h. 10 years previously.

Methods of Analysis

As previously mentioned, analysis of the basic data followed, in general, the planned routine. Few departures, indicated preferable by later developments, were made.

Determination of Normal Diameter Growth

Tree diameter increment consists of two parts--growth of wood and growth of bark. In this study the former was based on the increment cores described previously. The period on which this growth is based is the decade immediately preceding tree classification and core extraction. For plots 1 to 14 this was the period 1929 to 1938 inclusive; for plots 15 to 30 it was 1930 to 1939 inclusive. This growth period, the most recent, was used in order to minimize the effect of change in tree class during the interval. It would have been desirable to have classified the trees as of the beginning of the growth period, but this was obviously impossible in this study which started at the end of that period.

From F. P. Keen's studies of climatic cycles it is clear that ponderosa pine growth during the years 1929 to 1939 was considerably less than normal. The same studies indicate that growth for the 30 years, 1900 to 1929 inclusive, was approximately normal. Averages based on the years 1929 to 1939 were adjusted to their estimated climatic normal by dividing them by the ratios given in table 7.

Study of influence of d.b.h. on diameter growth rate consisted of simple, graphic correlation, tree class by tree class.

Growth of Bark

This phase of the study was based on 1,437 bark-thickness measurements taken on the permanent growth plots during the field season of 1941 by F. P. Keen and R. C. Grant. Since its results contribute to the understanding of diameter increment they are summarized here. A multiple correlation of bark thickness was computed as:

Table 10.--Location of Permanent 10-acre Sample Plots of the
Bureau of Entomology and Plant Quarantine

Plot No.	Forest	Location	Forty	No. trees on plot	Site index	Gross volume per acre
					Feet	M Bd.Ft.
1	Crater Lake N.P.	T. 29 S., R. 6 $\frac{1}{2}$ E., Sec. 21	16	215	81	26
2	" " "	" " " "	1	334	84	37
3	Fremont N.F.	T. 37 S., R. 16 E., Sec. 17	1	273	73	11
4	" " "	" " " "	2-3	198	74	11
5	" " "	T. 39 S., R. 13 E., Sec. 5	12	350	70	16
6	" " "	" " " "	2	258	67	8
7	Lost Forest	T. 25 S., R. 20 E., Sec. 27	21	133	62	4
8	" " "	" " " "	3	92	57	5
9	Deschutes N.F.	T. 12 S., R. 9 E., Sec. 35	3	299	85	18
10	" " "	" " " "	5	265	82	21
11	" " "	T. 21 S., R. 9 E., Sec. 35	10	337*	84	17
12	" " "	" " " "	9	516**	87	23
13	Ochoco N.F.	T. 12 S., R. 20 E., Sec. 32	15	302	78	28
14	" " "	" " " "	16	123	87	15
15	Umatilla N.F.	T. 6 S., R. 27 E., Sec. 16	5	256	76	17
16	" " "	" " " "	3	212	83	16
17	Malheur N.F.	T. 11 S., R. 28 E., Sec. 26	5	392	84	23
18	" " "	" " " "	14	262	86	24
19	Whitman N.F.	T. 12 S., R. 36 E., Sec. 3	3-4	288	87	26
20	" " "	" " " "	1	244	84	19
21	Ochoco N.F.	T. 21 S., R. 25 E., Sec. 17	13	230	75	11
22	" " "	" " " "	4	310	72	12
23	" " "	T. 18 S., R. 20 E., Sec. 10	4	293	78	18
24	" " "	" " " "	2-3	234	78	15
25	Fremont N.F.	T. 29 S., R. 12 E., Sec. 25	15	323	77	21
26	" " "	" " " "	10	429	68	19
27	Deschutes N.F.	T. 25 S., R. 12 E., Sec. 25	8	203	64	8
28	" " "	" " " "	2	185	66	9
29	Mt. Hood N.F.	T. 3 S., R. 11 E., Sec. 26	16	217	78	12
30	" " "	" " " "	14	214	83	16

* Experiment Station plot 27

** " " " " plot 28

NOTE: "No. of trees" includes those 7.6+ inches in d.b.h.
for plots 11 and 12, and 9.6+ for the other plots.

Table 11.--Number of Trees of Which Growth Measurements Were Analyzed, by Tree Class

Age class	Vigor class				Total
	A	B	C	D	
	Number of trees				
1	130	447	272	53	902
2	233	605	561	131	1,530
3	324	1,520	1,503	532	3,879
4	185	602	630	144	1,561
Total	872	3,174	2,966	860	7,872

Table 12.--Average Diameter of Trees Measured, by Tree Class

Age class	Vigor class			
	A	B	C	D
	Inches			
1	12.9	12.0	10.8	10.1
2	19.8	16.6	13.5	11.1
3	28.2	24.8	20.0	14.4
4	34.8	31.3	26.8	19.8

Double bark thickness at b.h. (inches) = .0787 d.b.h. ob. - .1615 age class - .1235 vigor class + 1.981

For convenience, vigor class has been given the following numerical designation: Vigor class A = 1, B = 2, C = 3, D = 4.

Translated into words, this formula says: (1) For trees of a given age and vigor class, bark is thicker, by a specified amount, the larger the d.b.h.; (2) for trees of a given size and vigor, bark is thinner the older the tree; and (3) for trees of a given size and age, bark is thinner the poorer the vigor. Bark thickness of ponderosa pines of any tree class and for any reasonable d.b.h. within that class can be computed by this equation. For example, that for a 25-inch 3B is estimated as:

$$(.0787 \times 25) - (.1615 \times 3) - (.1235 \times 2) + 1.981 = 3.217 \text{ inches.}$$

Based on d.b.h., inside bark, the equation for bark thickness is:

Double bark thickness at b.h. (inches) = .08542 d.b.h. ib. - .1615 age class - .1235 vigor class + 2.0869

An example will serve to illustrate the use of these equations for estimating the growth of bark that normally accompanies a given increase in diameter of wood. Take, for example, a 17-inch 2B, for which the estimated normal d.b.h. growth of wood for the next 20 years is 1.82 inches.

The present d.b.h. ib. of this tree is estimated as : 17 inches - present double bark thickness, or

$$17 - (.0787 \times 17 - .1615 \times 2 - .1235 \times 2 + 1.981) = 14.25 \text{ inches.}$$

During the 20 years the d.b.h. ib. is expected to increase from 14.25 inches to $14.25 + 1.82$ inches, or to 16.07 inches. Let us assume that during this 20-year period vigor class remains the same, i.e., class B. Age class, however, will increase $20 \div 100$ or .2 of a class interval to 2.2. Then, d.b.h. ob. 20 years hence would be estimated as:

$$16.07 + (.08542 \times 16.07 - .1615 \times 2.2 - .1235 \times 2 + 2.0869) = 18.93 \text{ inches.}$$

If growth of wood only had been allowed for, d.b.h. ob. 20 years hence would have been estimated merely as 17 inches, the present d.b.h. ob. + 1.82 inches, the estimated growth of wood, or 18.82 inches. The difference in estimated growth of diameter outside bark is 1.93 inches - 1.82 inches, or .11 inches, an increase of 6 percent, due to the allowance for growth of bark.

Permanent sample plot examiners express surprise at trees that decrease in d.b.h. measurement between examinations. Such occurrences usually have been rightly attributed to errors of measurement, but the above bark thickness equations indicate that diameter shrinkage may sometimes be real and logical.

Let us take, for example, a 20-inch, class 3C of waning vigor. Such a tree, if it survives, will make a d.b.h. ib. increment of perhaps .05 inches per decade as it declines into the next lower or D-vigor class. The first equation indicates present double bark thickness of this tree is:

$$(.0787 \times 20) - (.1615 \times 3) - (.1235 \times 3) + 1.981 = 2.70 \text{ inches.}$$

Present d.b.h. ib. would then equal 20.00 - 2.70 or 17.30 inches. If d.b.h. ib. grows to 17.35 inches during the next decade while vigor drops to class D, bark thickness 10 years hence would be estimated as:

$$(.08542 \times 17.35) - (.1615 \times 3.1) - (.1235 \times 4) + 2.0869 = 2.57 \text{ inches.}$$

The present dimensions of this tree and those estimated for 10 years hence are tabulated below:

<u>Time</u>	<u>Tree class</u>	<u>D.B.H. ob.</u>	<u>D.B.H. ib.</u>	<u>Bark thickness</u>
Now	3C	20.00	17.30	2.70
10 years hence	3D	19.92	17.35	2.57

The equations indicate that loss of bark by sluffing would exceed bark increment from cambial activity during a period of such slow growth, and that d.b.h. ob. would actually shrink even while d.b.h. ib. made a small increase.

Allowance was made for growth of bark in the growth estimates by the following equation which was derived from the two above:

$$10\text{-year growth in d.b.h. ob.} = 1.08542 (10\text{-year growth in d.b.h. ib.}) - .01615.$$

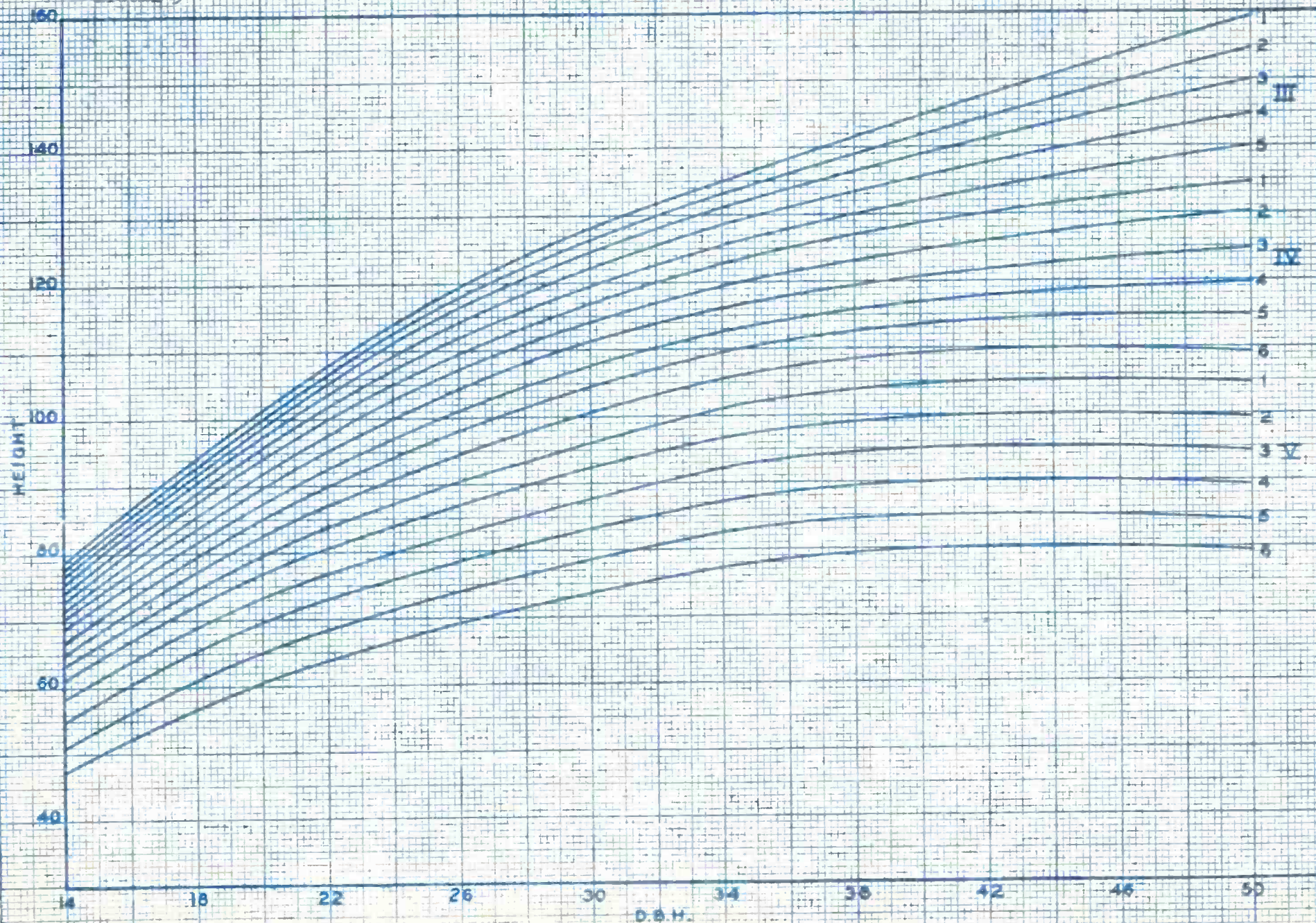
Conversion of D.B.H. Growth to Volume Growth

The volume tables to which diameter increments were applied were derived from the range-wide tables for ponderosa pine. Tables for immature pine were used for age classes 1 and 2, those for mature pine for age classes 3 and 4. The ponderosa pine table for mature trees is based on site quality class, and an average of the published values for class IV- and class IV+ were used as class IV medium.

The height curve employed was number IV 3 from figure 5 which shows the harmonized height over diameter curves developed by Keen and Grant. Using this height curve and the above standard volume tables, medium site IV volume tables based on d.b.h. only were prepared. Volumes corresponding to each 1-inch d.b.h. class were tabulated and those corresponding to each 1/10-inch d.b.h. were arithmetically interpolated. In all, four tables in this form were used:

FIGURE 5

HEIGHT CURVES FOR ADJUSTED VOLUME TABLES



Immature trees

1. Board feet, Scribner rule, to 8-inch top.
2. Cubic feet, entire stem.

Mature trees

3. Board feet, Scribner rule, to 8-inch top.
4. Cubic feet, entire stem.

The normal 10-year diameter increments given in table 2 were applied to the appropriate volume tables and 10-year growth per tree was computed in terms of both board feet and cubic feet. Annual growth percent as here used equals:

$$\frac{(\text{10-year volume growth}) 10}{\text{volume at start of 10-year period}}$$

Computed volume growth percentages were harmonized graphically and recorded in tables 5 and 6. Final volume growth values in absolute units were then derived by applying the harmonized growth percentages to the appropriate volume table values.

Analysis of Effect of Site and Stocking

For each plot, total radial growth of all trees was divided by the expected radial growth and multiplied by 100. Expected radial growth in this instance was that which the plot would have made had each tree on it grown at the rate for its class, based on the average of all plots. These percentages were correlated with site index and gross volume per acre of the plots to which they applied in a multiple analysis, and residuals tested for curvilinearity. None was found.

Similar analyses were made for each of the periods 1929-39, 1900-19, and 1900-29, but in no instance did the variable of volume per acre show significant relationship with growth. Net relationships between growth and site index that were obtained are given in table 9.

As previously mentioned, the basic data were not selected with a specific objective of disclosing effect of site and stocking on growth, and the correlations between growth and these two variables were not found to be strong. Association with site, however, is somewhat closer than that with stocking. The correlation coefficient expressing the association between site index and radial growth is .35, and is barely significant.

Variation in Growth Rate Within Classes

In spite of the comparatively intensive classification of trees under the Keen system, the fact remains that trees are individuals and as such exhibit an almost infinite variety of characteristics--including growth rates. Obviously it is impossible for any class average to express accurately the growth rate of every individual tree within that class--some will grow more rapidly, some more slowly, even during normal climatic cycles. The standard errors of estimate given in table 13 indicate the variation in diameter growth rate within tree classes that remains after accounting for differences in tree size and site quality. For example, as shown in table 2, the normal diameter growth rate for a 30-inch class 3B tree is .76 inches per decade. But, as indicated by table 13, one out of three such trees, on the average, may be expected to exceed or fall short of this growth rate by at least 44 percent of .76 inches. In other words, two-thirds of the 30-inch 3B trees may be expected to make growth rates ranging between 1.10 inches and .43 inches. It is evident that a large part of the variation in tree growth is still unexplained.

Although the growth rates within tree classes vary widely, differences between tree-class averages nevertheless are substantial and statistically highly significant.

The relative variation in growth rate is greater, in general, for the slower-growing tree classes, smaller for the more rapidly growing.

Table 13.--Standard Error of Estimate of Diameter
Growth Rates for Individual Trees
as Percent of Class Average

Age class	Vigor class			
	A	B	C	D
	Pot.	Pot.	Pot.	Pot.
1	32	40	56	60
2	39	47	70	80
3	49	44	68	59
4	63	64	68	71